The Effect of Implicit Context on Memory Integration

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ABSTRACT

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While recent work has shown implicit context effects on memory (i.e. memory effects of learning in a shared context without testing the item-context association) in recall and recognition, none have used shifts in natural environments, limiting the translation of these findings to real learning environments. Further, the role of implicit memory in memory integration, the process of bridging across related experiences through the extraction of overlapping features, has not been described. This study examines the degree to which implicit context influences the ability to bridge across related experiences to form integrated memories, using associative inference as a behavioral measure of memory integration. In Experiment 1, an across subject's associative inference task described by Preston et al, was used to examine implicit context effects on memory integration. In this task initial pairs (AB) were learned in one context followed by the learning of overlapping (BC) and non-overlapping (XY) pairs in the same or different context. Following learning of the overlapping AB and BC pairs, participants were asked to infer the indirect AC relationship. We found both a significant facilitation of the BC learning as compared to XY learning and reduction in response time when the AB and BC pairs had been learned in the same context. To test the individual variance in the encoding of implicit context, in Experiment 2 we used a within subject design. We found that while there was no significant effect of context shift on the inference task, there was a facilitation of the overlapping pair (BC) learning as compared to nonoverlapping pairs (XY) when they were learned in the same environment as the overlapping AB pairs. The inability to replicate the effect on inference, may be attributed to the added contextual shift before the AC inference test. Thus, we hypothesize that the context of the inference test may also be vital in facilitating implicit context effects on memory. Importantly we found that implicit context exhibits memory effects in an associative inference design, affecting the speed with which inferences are made, suggesting that shared implicit context is important in facilitating memory integration.

The Effect of Implicit Context on Memory Integration

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While recent work has shown implicit context effects on memory (i.e. memory effects of learning in a shared context without testing the item-context association) in recall and recognition, none have used shifts in natural environments, limiting the translation of these findings to real learning environments. Further, the role of implicit memory in memory integration, the process of bridging across related experiences through the extraction of overlapping features, has not been described. This study examines the degree to which implicit context influences the ability to bridge across related experiences to form integrated memories, using associative inference as a behavioral measure of memory integration. In Experiment 1, an across subject's associative inference task described by Preston et al, was used to examine implicit context effects on memory integration. In this task initial pairs (AB) were learned in one context followed by the learning of overlapping (BC) and non-overlapping (XY) pairs in the same or different context. Following learning of the overlapping AB and BC pairs, participants were asked to infer the indirect AC relationship. We found both a significant facilitation of the BC learning as compared to XY learning and reduction in response time when the AB and BC pairs had been learned in the same context. To test the individual variance in the encoding of implicit context, in Experiment 2 we used a within subject design. We found that while there was no significant effect of context shift on the inference task, there was a facilitation of the overlapping pair (BC) learning as compared to nonoverlapping pairs (XY) when they were learned in the same environment as the overlapping AB pairs. The inability to replicate the effect on inference, may be attributed to the added contextual shift before the AC inference test. Thus, we hypothesize that the context of the inference test may also be vital in facilitating implicit context effects on memory. Importantly we found that implicit context exhibits memory effects in an associative inference design, affecting the speed with which inferences are made, suggesting that shared implicit context is important in facilitating memory integration.

We live in a constantly changing environment, thus our ability to adapt and integrate our knowledge in response to these changes is essential. One such adaptive mechanism is memory integration[3], which underlies our ability to bridge across overlapping experiences by extracting shared features[5,7,12]. Integration is thought to occur when new learning cues the reactivation of a related memory, leading to the creation of a more overlapping representation[11]. For example, if you see a man walking a dog at a park and then see a woman with the same dog at that park, you might infer that they are both caretakers of the dog and be related in some way. If, however, you saw the woman with the dog in a different context, like at your office, you may find it more difficult to make this inference. This study aims to examine the degree to which implicit context, influences the ability to make inferences (i.e. memory enhancement by shared learning environment without testing for explicit item-context association).

Early work by Greenspoon and Ranyard in 1957 examined the role of shifts in implicit context or the environment in which people learn, in a list-learning free recall test. In their list-learning free recall design, participants were asked to learn and recall as many items from two lists of nonsense syllables learned either in shared or differing contexts. They showed that varying the original location of learning and relearning of the list reduced interference by retroactive inhibition[2]. Similarly, Godden and Baddeley[1] showed a reduction of retroactive inhibition when the two lists were learned in different natural contexts, on land and underwater, suggesting that shared context information across memories results in a greater degree of interference, inhibiting the recall of previous learning. Eich[3] demonstrated that the degree to which context acts as a cue in the free recall of items is dependent on the degree that context is involved in the encoding process. They show that a top-down manipulation of encoding strategy by explicit instruction to use context as a recall cue can result in greater integration of the item/context imagery and a higher dependency on the context as a recall cue when the contexts were shared between learned lists[3]. Finally, Zhang et al.[9] tested the importance of context in a face recognition task where at test the faces were presented either the same background context as at learning or a different context[9]. The authors found increased connectivity between IFG and face and place-responsive areas (FFA/amygdala and PPA) in strongly contextualized memories, suggesting that the IFG is involved in integrating information across widespread regions representing distinct aspects of a memory, likely including perceptual features, spatiotemporal context, and motivational salience[9]. They also found that PFC and hippocampus are involved in contextualization of implicit contexts during encoding, resulting in subsequent effects of context on recognition. This suggests that contextual processing at encoding of events is critical for retrieval[9].

While recent work has examined implicit context effects on memory in recall and recognition, none have used shifts in natural environments as seen in early work[1,2], limiting the translation of these findings to real learning environments. Further, while the role of implicit context as a recall cue and in generating interference by retroactive inhibition has been illustrated[1,2,3,9], its role in cueing the formation of integrated memories through reactivation of overlapping memory has not been examined. We hypothesize that the overlap in the context causes greater reactivation of the previous memory, causing the formation of more integrated memories. This study examines the degree to which implicit context influences the ability to form integrated memories using associative inference as a behavioral measure of memory integration[11,12].

In order to test the effect of implicit context on memory integration we adapted the associative inference task described by Preston et al.[4,6] (Figure 1) by introducing a context shift between the learning of initial associate pairs (AB) and overlapping associate pairs (BC). We examined the impact of the context shifts on integration by examining accuracy and response time on an associative inference task[11,12].

In Experiment 1, an across-subjects design demonstrated that learning the overlapping pairs in a different context impaired the ability to perform the associative inference task. We found a significant facilitation of the learning of the overlapping pairs (BC) as compared to the nonoverlapping (XY) pairs only when they shared the original learning context as the AB pairs. Further, shared context led to a faster response time in the associative inference task, suggesting that shared context facilitated integration. The effect of shared context on integration was shown to be sensitive to the degree of context similarity and not due to a disruption or differential rehearsal. To control for individual difference in the encoding of context, in Experiment 2 a within-subjects design was used to test the effect of context shift on the ability of individuals to perform associative inference. Similarly, to Experiment 1, learning of the overlapping pairs was facilitated only when the learning contexts were shared. Contrary to the previous result, however, we found that context shift did not significantly affect the ability to perform the associative inference. The inability to replicate the effect on inference, may be attributed to the

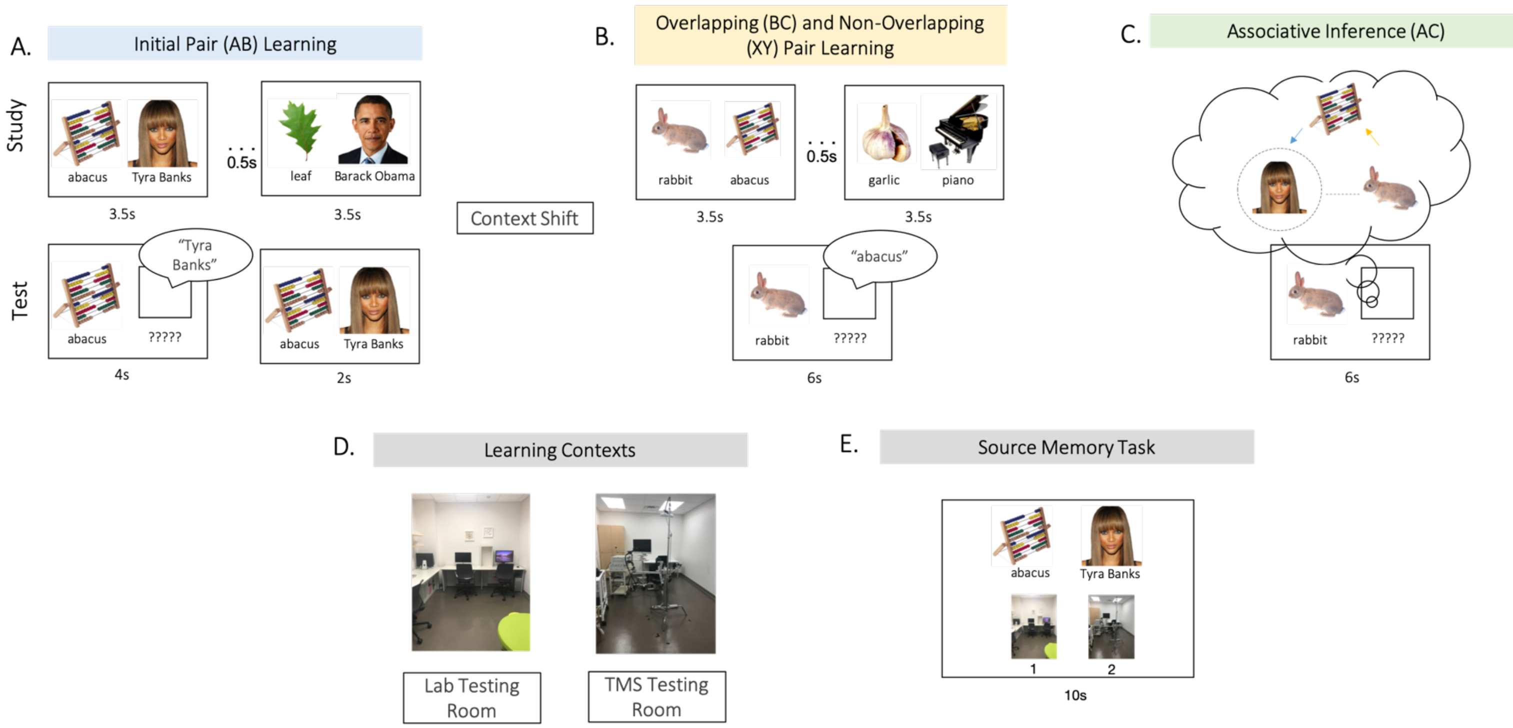

Figure 1 | Schematic of One-Day Associative Inference Task with Implicit Context Shift. A. Participants learned the initial AB pairs over three study test repetitions. In the study phase, participants were presented with the associate pairs of common objects (B) and people (A), with the object presented on the left and the celebrity on the right, for 3.5 seconds each with a 0.5s Inter-Trial Interval (ITI). Each study was followed by a cued-recall test where participants were asked to verbally respond with the person paired with the presented object cue in a 4 second period. They were then presented with the correct answer for 2 seconds. The order of learning and testing of the pairs was randomized across the study/test runs. **B.** Following the learning of the initial pairs, one group was shifted to a new context and the other remained in the same context. Participants were instructed to learn new pairs of common objects in one study/test run, half of the object pairs overlapped with the initial pairs (BC) and half did not overlap (XY). During the test phase, participants were presented with the C or Y item and asked to verbally respond with the object pair. **C.** In the associative inference task, participants were presented with the C item, here the rabbit, and given 6 seconds to respond verbally with the person that was indirectly linked to that object (A item), requiring that they

added contextual shift for the inference task. We hypothesize that the context of the inference test may also be vital in facilitating implicit context effects on memory.

Experiment 1

Methods

Participants. Seventy individuals from the University of Texas at Austin participated in the experiment after giving informed consent in accordance with a protocol approved by the Institutional Review Board. Participants received partial course credit as compensation. Three participants were removed from the final analysis because they did not follow the task instructions. The final sample of participants (n_{within} = 28, n_{across} = 25, 43 females) had a mean age of 18.9 years (range 18-21 years).

Stimuli. Stimuli consisted of 40 pictures of celebrities (20 female and 20 male) and 120 pictures of pictures of common objects overlaid on a white background. The pictures were organized into 40 ABC triads consisting of a celebrity A item and objects as the B and C items. The triads were learned in separate experimental phrases by studying overlapping AB and BC pairs. The triads were never explicitly shown to participants. In addition to the 40 overlapping BC items, 40 non-overlapping XY pairs composed of two objects were presented to measure the degree to which the shared context facilitated the learning of overlapping. If learning of subsequent overlapping information reactivates the previous memory for the formation of an integrated memory, we would predict improved learning in the overlapping (BC) pairs not seen in the non-overlapping (XY) pairs. All stimuli were presented in color. The stimuli were presented with MatLab using PsychToolBox.

Testing Rooms. Two perceptually different testing rooms were used: the testing room in the lab space and the Transcranial Magnetic Stimulator (TMS) testing room in the Imaging Research Center at the University of Texas at Austin, depicted in Figure 1D. The perceptual similarity of the contexts differed. The lab testing room had a closed door with no windows, paintings, computers, children's toys on a shelf, and a small colorful table in the corner. The TMS testing room was had no painting or decorations, white bare walls, and a TMS device in the center of the room.

Procedure. An associative inference task based on the Schlichting and Preston[6] was used to behaviorally test memory integration, using a context shift based on the Godden and Baddley[1]design. Participants first learned AB associations, then either shifted contexts or remained in same context for learning of the overlapping (BC) and nonoverlapping (XY) pairs. The starting context was counterbalanced across participants. Finally, participants completed an associative inference task (AC) in the same learning context as the BC and XY pairs. Across sessions, participants interacted with the same experimenter.

Initial pair (AB) learning. Participants were instructed to learn AB associations in a computer task (Figure 1A). Three study-test runs were given for maximal learning. During the study phase, each AB pair was presented on screen for 3.5 seconds with a 0.5 second inter-trial interval (ITI). The A item was always presented on the right side of the screen and the B items were presented on the left side. Labels for each person and object were presented underneath the stimuli. Following each study phase, participants performed a randomly ordered cued-recall test, where the B item and label was presented on the left side of the screen. Participants responded verbally with the A associate within 4 seconds of cue presentation. They were then were provided with the correct answer for 2 seconds with a following 0.5 second ITI. All responses were recorded using a microphone.

Overlapping (BC) and non-overlapping (XY) pair learning. Following the initial pair learning, one group of participants were moved to a novel context (shift condition) while the other remained in the initial learning context (no shift condition). In the shift condition, participants talked with the experimenter while waking to the second context. In the no shift condition, the participants were asked to leave the room and perform a 2-minute simple arithmetic task while the experimenter "set up the next part of the experiment." The distractor task was performed to equate the disruption and time between learning the initial and overlapping pairs in the shift condition. All participants were instructed to learn new pairs in one study phase. During this phase, they learned set of associate pairs consisting of the overlapping (BC) pairs and the non-overlapping (XY) pairs (Figure 1B). The BC and XY pairs were intermixed and randomly presented once each for 3.5s with 0.5 seconds between pairs. Following the study phase, participants completed a test phase. In the test phase, the B/X items were presented on the left side of the screen and participants were given 6s to respond verbally with the object paired with the item presented (C/Y items). The correct item was not shown.

Associative Inference Test (AC). Finally, in the same learning context as the overlapping pair (BC) learning, participants completed an associative inference task, testing their ability to infer the indirect relationship between the A and C items due to the shared B item (Figure 1C). At the beginning of the task, participants were shown an example of the triad structure and instructed to respond with the indirectly related person (A item) when cued with the C item, a common object. The cue item was presented on the left side of the screen and participants were given 6s to respond verbally with the indirectly related A item. Importantly, the A and C items were never presented together. Participants were explicitly instructed on how to perform the inference task directly before the test. No learning or testing strategies were suggested.

Analysis. Audio data from the cued-recall tests were annotated and scored using Penn Total Recall (memory.psych.upenn.edu/TotalRecall).
Response time was determined using the vocal onset of the response, excluding vocalizations such as "um" or "uh". Full names and partial names (i.e. "Gomez" for Selena Gomez, or "fridge" for refrigerator) were marked as correct given that they were linked to only one of the celebrities (i.e. "Harry Potter" was accepted for Daniel Radcliffe, but "Batman" was not accepted because both George Clooney and Christian Bale held this role).
The effect of the implicit learning context shift on recall accuracy and response time, calculated as the median of the correct responses, was determined using repeated-measures analysis of variance (ANOVA) two-tailed paired t-tests. Data analysis was conducted in Matlab and in Excel. T-tests are reported with 95% confidence intervals (CI) of the differences (across-within). Means are reported with 95% confidence intervals.

Results

Initial Pair (AB) learning. Participants learned the AB pairs to an average of 87% recall (df = 30, CI = [80%,93%]) in the within condition and 87% recall (df = 30, CI = [80%,95%]) in the across condition (Figure 2), by the end of learning. These results, taken together with the decreasing response time across trials, seen in Figure 2A, suggest that participants learned the initial pairs well by the end of the initial pair learning.

Overlapping (BC) and nonoverlapping (XY) pair learning. The accuracy and response time of the overlapping and non-overlapping pairs for both those learned within the same context as initial pairs and in a different context is displayed in Figure 2B. To test the effect of the context shift on pair learning, the recall and response time (BC_{across}, XY_{across}, BC_{within}, XY_{within}) to separate two-factor repeated measures ANOVAs with overlap type (BC vs XY) and context shift (across vs within) as factors. There was a significant difference in recall accuracy between BC and XY ($F(1,25) = 7.26$, $p = 0.013$). There was no effect of the context shift ($F(1,25) = 0.61$, $p = 0.44$) and there was no interaction between the overlap and context shift ($F(1,25) = 0.29$, $p = 0.59$). There was no effect of the context shift on response time ($F(1,25) = 0.11$, $p = 0.74$) no effect of the overlap on response time ($F(1,25) = 1.70$, $p = 0.20$), and no interaction between the two independent variables ($F(1,25) = 1.42$, p =

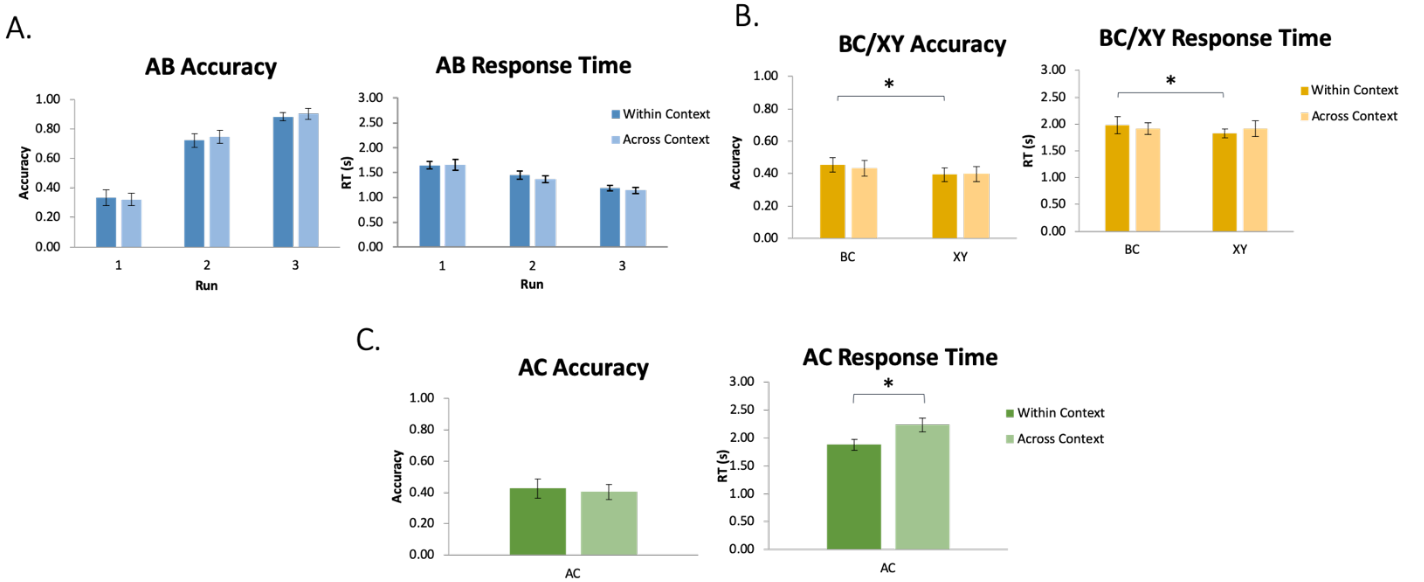

Figure 2 | Experiment 1 Results. A. Accuracy and Response Time (seconds) are displayed for all three runs of the initial pair (AB) learning. There is an increase in accuracy and decrease in response time in each subsequent trial, consistent with learning of the pairs. **B.** Accuracy and response time are shown for both the overlapping (BC) and non-overlapping (XY) pairs. There was significant difference between the accuracy and response time in BC and XY pairs learned within the same context as the initial pairs (AB), suggesting an increased response time for the overlapping pairs. **C.** The accuracy and response time for the inference test are displayed, showing a significant effect of the context shift on the response time ($p = 0.013$). Two-sample equal variance t-tests were used for across

0.25). Paired t-tests with two-tailed distributions revealed a significant difference between response time ($t(26) = 10.50$, $p = 0.037$, CI = [0.004,0.12] and accuracy ($t(26) = 10.60$, $p=0.035$, CI = [0.02,0.37] of the overlapping and nonoverlapping (BC/XY) pairs only in the within context learning. The BC and XY pairs did not differ significantly in the across condition for response time ($t(24) = 0.29$, $p = 0.95$, CI =[-0.23,0.24]) or accuracy ($t(24) = 7.64$, $p = 0.12$, CI = [-0.01,0.08]). Levene's Test was run for each two-sample t-test in order to test equal variance before conducting two-sample t-tests. Two-sample t-tests with equal variance with two-tailed distributions were run revealing that BC accuracy ($t(51) = 0.14$, $p = 0.75$, CI = [-0.31,0.27]) and response time ($t(51) = 0.20$, $p = 0.63$, CI = [-0.75,0.61]) did not differ based on the context shift. Similarly, the XY accuracy ($t(51) = 0.015$, $p = 0.96$, CI = [-0.31 0.31]) and response time($t(51) = 0.43$, $p = 0.37$, CI = [-0.51,0.79]) did not differ due to the context shift. These results show that shared context facilitated new learning when it overlaps with prior knowledge.

Inference (AC) Performance. Performance on the inference test is displayed in Figure 2C. A two-sample t-test with equal variance and a two-tailed distribution revealed a significant effect of the context shift on response time, with an increased response time in the shifted context condition ($t(51) = 0.92$, $p=0.013$, CI= [-0.41,1.09]). This affect remained when conditionalized to only include inferences made when the participants had learned both the AB and BC pairs ($t(51) = 0.49$, $p =0.065$, CI = [-0.72,1.23). There was not a significant effect of the context shift on accuracy ($t(51) = 0.21$, $p = 0.83$, CI = -0.09,0.07]). Together, these results suggest that the overlapping context facilitates

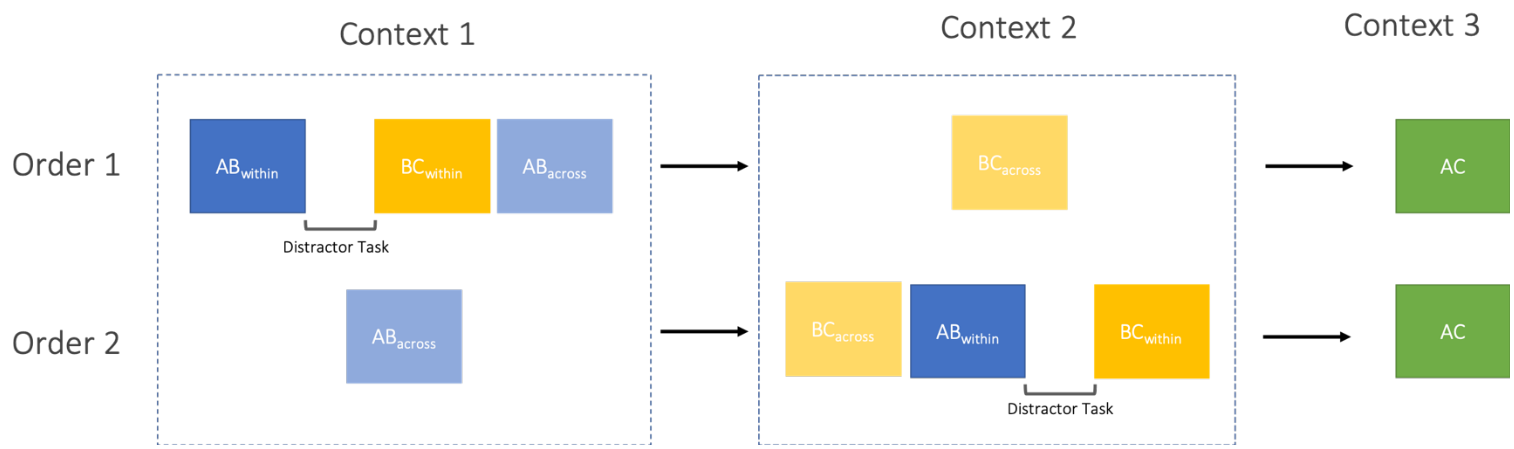

Figure 3 | Experiment 2 Within Subjects Experimental Design. A 2x2 design with 2 orders using order crossed with context was used to counterbalance the order of the context shift and control for effects of recency[1]. Half of the participants learned AB_{within}, BC_{within}, AB_{across} in the first context before shifting to learn BC_{across} in the second context. The other half first learned AB_{across} first in the first context, then shifted to the second context to learn BC_{across}, AB_{within}, BC_{within}. All participants were then moved to a third location with no previous learning for the inference test A two-minute distractor task was used between learning the AB and BC/XY pairs in the within-context shift condition to equate the disruption and potential differential rehearsal of the initial pairs.

learning of the overlapping pairs (BC) resulting in an increased speed of response in the inference test.

Discussion

These results suggest that shared implicit context facilitates learning of new pairs when they overlap perceptually with prior knowledge, speeding inference decisions. These results are consistent with the idea that shared context facilitated memory integration.
However, contrary to what we would predict given that the shared context facilitated BC learning, recall of the BC items was slower in the shared context condition. We hypothesized that variation within the population in the ability to perform the inference task or the importance of binding implicit context resulted in the slowing of the BC recall and minimized the strength of the effect of implicit context on AC inference.
Thus, in Experiment 2 we performed the same experimental manipulation of implicit context in a within-subjects design. We also included a source memory task in order to determine if the implicit context was being encoded.
Additionally, we changed the inference (AC) testing location to a third neutral or new location in order to control for any facilitation caused by testing in the same environment as the BC/XY pairs were learned.

Experiment 2

Methods

Participants. Thirty-one individuals (21 females) with mean age of 18.8 years (range 18-21 years) from the University of Texas at Austin participated in the experiment after giving informed consent in accordance with a protocol approved by the Institutional Review Board. Participants received partial course credit as compensation.

Stimuli. Stimuli consisted of the same 40 pictures of celebrities (20 female and 20 male) and 120 pictures of pictures of common objects overlaid on a white background used in

Experiment 1. The pictures were organized into two 20 ABC triads consisting of a celebrity A item and object B and C items. The triads were learned in overlapping experimental phrases by studying overlapping AB and BC pairs. In addition to the 40 overlapping BC items, 40 non-overlapping XY pairs composed of two objects were presented.

Testing Rooms. Three perceptually different testing rooms were used. In addition to the contexts used in Experiment 1, a third location that had no previous learning was used for the inference (AC) test. This testing room at the University of Texas at Austin had large open windows with natural lighting, carpet, and band posters. Participants were consistently oriented towards the open window.

Procedure. In order to examine the extent of individual variance in the effect of the implicit context shift on associative inference, a within subjects' variation of the associative inference task was used (Figure 1). This design consisted of initial pair (AB) learning, overlapping (BC) and non-overlapping (XY) pair learning, and an inference test (AC) as described in Experiment 1. However, in Experiment 2 each participant learned initial and overlapping pairs both within and across contexts. Participants learned 20 triads with a context shift and 20 triads without a context shift between the initial pair (AB) learning and overlapping (BC) and non-overlapping (XY) pair learning. A 2x2 design using order crossed with context was used to counterbalance the order of the context shift and control for effects of recency[1]. Half of the participants learned AB_{within}, BC_{within}, AB_{across} in the first context before shifting to learn BC_{across} in the second context. The other half first learned AB_{across} first in the first context, then shifted to the second context to learn BC_{across}, AB_{within}, BC_{within}. All participants were then moved to a third location with no previous learning for the inference test (Figure 3). A two-minute distractor task was used between learning the AB and BC/XY pairs in the within-context shift condition to equate the disruption and potential differential rehearsal of the initial pairs[1].

Source Memory Test. Finally, to determine if participants encoded context information, participants completed a source memory task on all the AB and BC/XY pairs learned. They were cued with the pairs and chose which room they thought they had learned them in (Figure 1E). The pairs were intermixed and presented in a random order.

Results

Initial Pair (AB) learning. Participants learned the AB pairs to an average of 95% recall (CI = [91%,98%]) in the within condition and 96% recall (CI = [92%,99%]) in the across condition (Figure 4A), by the end of learning. These results, taken together with the decreasing response time across trials, seen in Figure 4A, suggest that participants learned the initial pairs well.

Overlapping (BC) and nonoverlapping (XY) pair learning.
The accuracy and response time of the overlapping and non-overlapping pairs for both those learned within the same context as initial pairs and in a different context is displayed in Figure 4B. To test the effect of the context shift on pair learning, the recall and response time (BC_{across}, XY_{across}, BC_{within}, XY_{within}) to separate two-factor repeated measures ANOVAs with overlap type (BC vs XY) and context shift (across vs within) as factors. There was a significant difference in recall between BC and XY ($F(1,60) = 4.98$, $p = 0.033$). There was no effect of the context shift on recall accuracy ($F(1,60) = 1.13$, $p = 0.29$) and there was no interaction between the overlap and context shift ($F(1,60) = 1.23$, $p = 0.28$). There was no effect of the context shift on response time

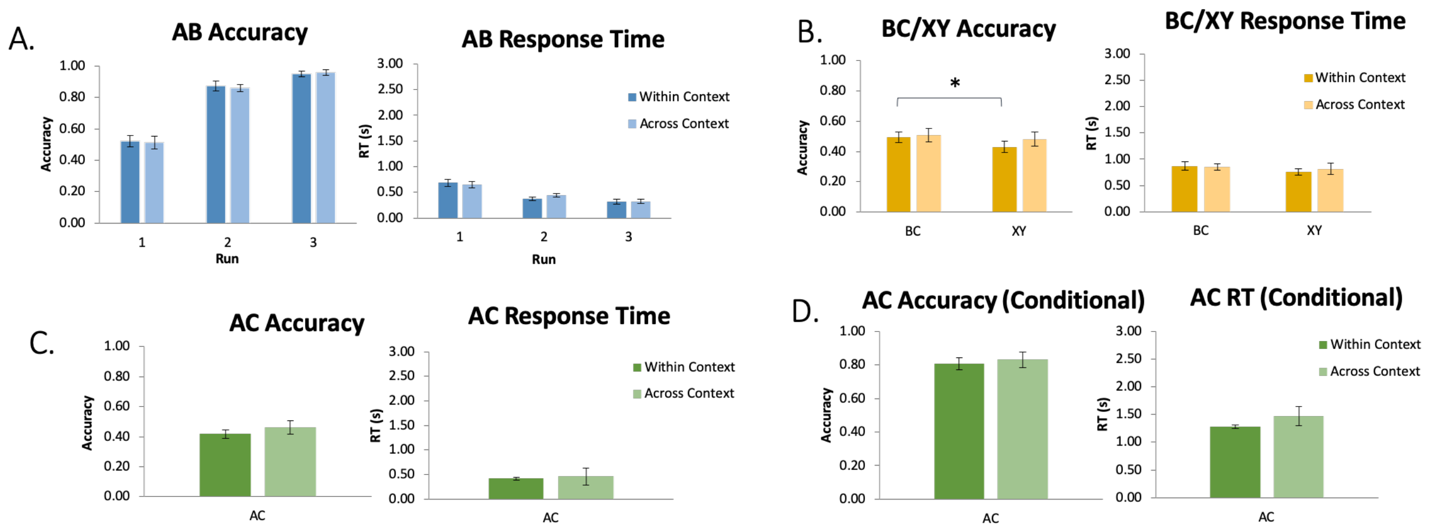

Figure 4 | Experiment 2 Results. A. Accuracy and Response Time displayed for all three runs of the initial pair learning. Participants learned the pairs by the third trial, with increasing accuracy and decreasing response time across runs. This replicates the results seen in experiment 1. **B.** Accuracy and response time are shown for both the overlapping (BC) and non-overlapping (XY) pairs. **C.** The accuracy and response time for the inference test are displayed. **D.** The AC performance given that both the AB and BC pairs had been learned are shown. Paired t-tests with two-tailed distributions were used in all analyses to assess statistical significance. * $p < 0.05$.

($F(1,60) = 0.08$, $p = 0.78$) no effect of the overlap on response time ($F(1,60) = 1.22$, $p = 0.28$), and no interaction between the two independent variables ($F(1,60) = 0.31$, $p = 0.58$).
Paired t-tests with a two-tailed distribution revealed a significant difference between accuracy of the overlapping (BC) and nonoverlapping (XY) pairs in the within context learning only ($t(29) = 11.19$, $p=0.035$, CI = [-0.12,0.00]). There was no difference in the accuracy in the across context condition ($t(29) = 6.15$, $p = 0.26$, CI = [-0.07,0.02]. There was also no difference between the BC/XY response time in the within condition ($t(29) = 6.46$, $p = 0.23$, CI = [-0.31,0.08]) or across condition ($t(29) = 1.79$, $p = 0.75$, CI = [-0.24,0.17]).There was no effect of the context shift on BC accuracy ($t(29) = 2.28$, $p = 0.68$, CI = [-0.06, 0.09]) or response time ($t(29) = 1.57$, $p = 0.78$, CI = [-0.20, 0.15]. There was also no effect of the context on XY accuracy ($t(29) = 7.81$, $p = 0.15$, CI = [-0.02,0.12]) and response time ($t(29) = 3.21$, $p = 0.56$, CI = [-0.14, 0.25]).

The significant difference of the learning of the BC and XY pairs in the within context condition suggest facilitation of the learning of the overlapping pairs when they were learned in the same environment as the initial pairs. Importantly, the effect on response time observed in Experiment 1 is not seen here, suggesting that is may be attributed to individual differences.

Inference (AC) Performance. Performance on the inference test is displayed in Figure 4C. A paired t-test with a two-tailed distribution revealed no significant effect of the context shift on response time ($t(29) = 5.78$, $p=0.29$, CI = [-0.15,0.5]), failing to replicate the effect seen in Experiment 1. There was also not a significant difference in response time when conditionalized to only include inferences made when the participants had learned both the AB and BC pairs ($t(29) = 6.59$, $p=0.23$, CI = [-0.12,0.51]). There was not a significant effect of the context shift on the accuracy of the performance in the unconditional ($t(29) = 6.26$, $p=0.25$, CI = -0.03,0.12]) and conditionalized

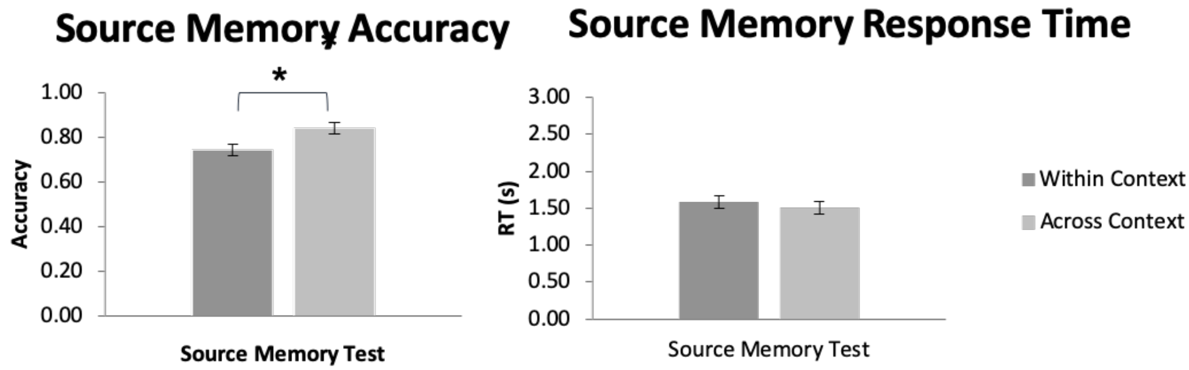

Figure 5 | Source Memory Results. The source memory accuracy and response times are displayed, showing a significant effect of the context shift on both the ability to localize the pairs accurately and the time taken to make these localizations. The across context was shown to be more accurate and take less time. A paired t-test with a two-tailed distribution was used to evaluate significance. * $p < 0.01$

analyses ($t(29) = 2.64$, $p = 0.63$, CI = [-0.07,0.12]). These results fail to replicate the significant effect observed of the context shift on the response time in Experiment 1.

Source Memory Performance. The results from the source memory task following the inference test are shown in Figure 5. A paired two-tailed t-test revealed that there was a significant effect of the context shift on the accuracy of source memory for the associate pairs ($t(30) = 13.44$, $p = 0.012$, CI = [-0.19,-0.03]). There was not a significant effect, however, of the context shift on the response time ($t(30) = 8.05$, $p = 0.14$, CI = [-0.03,0.18]). When analysis was conditionalized to only include the pair types that had been learned in different contexts (i.e. if all the people had been learned in the first room, only the source memory for the object pairs was examined) the effect of the context shift on accuracy remained ($t(30) = 22.77$, $p = 8.76E-07$, CI = [-0.47,-0.24]) and there was an effect of the shift on the response time ($t(28) = 18.83$, $p = 7.11E-05$, CI =[0.26,0.67]). These results indicate an increased accuracy and increase response time for source memory for the pairs that had been learned in a separate context from the originally learned pairs.

Discussion

In Experiment 2, there was significant facilitation of the overlapping pairs (BC) only in the condition in which those pairs were learned within the same context, suggesting that shared implicit context aids in the facilitated learning of new pairs when then overlap perceptually with prior knowledge. Further, the increased response time for the overlapping pairs seen in Experiment 1 was not replicated in Experiment 2. Thus, as we predicted, the previous result is most likely attributed to individual variation in the encoding of implicit context.

Despite the facilitation of BC learning, Experiment 2 failed to replicate the effect of the implicit context shift on the response time in the AC inference seen in Experiment 1. One possible explanation for this is the introduction of the novel location for the AC inference. Perhaps testing in the same location as BC learning facilitated inference increasing the speed with which participants responded. Regardless, in both experiments learning the overlapping items in the same context facilitates learning of the overlapping pairs (BC), potentially resulting in increased integration of the overlapping memories through the increased reactivation of the initial pairs.

Further, the significant effect of the context shift on the encoding of the context provides evidence that the participants were encoding the context as a part of the memory, but that the accuracy and speed at which these source memory decisions were made were greatly increased in the AB_{across} and BC/XY_{across} pairs. This increased accuracy and speed suggests that the disruption of the context shift, or novelty of the new context, may act to increase the behavioral relevance and thus encoding of implicit contextual information

General Discussion

This work uses an ecologically valid experimental design inspired by Godden and Baddeley's canonical 1975 experiment. Thus, our findings translate more readily to an educational setting where learning contexts change often across learning and testing of related information. Further, while previous work has examined the role of overlapping context in producing interference in subsequent learning[2], none have examined the role of context in the formation of integrated memories. The facilitation of overlapping learning compared to non-overlapping learning (BC-XY) in Experiment 1 occurred only when they shared learning context with the initial pairs (AB). We also observed an increased response speed in the inference test, suggest that the implicit context implicit context facilitates learning of new pairs when they overlap perceptually with prior knowledge, speeding inference decisions. These results are consistent with the idea that shared context facilitated memory integration. In Experiment 2, we observed the same facilitation of overlapping learning (BC-XY) only when learned in the same context as prior learning. Experiment 2, however, failed to replicate the implicit context effect on associative inference. This could be due to the added contextual shift after BC/XY learning to a novel context for the AC inference test. Further, the greater encoding of the implicit context when there was a shift in context suggests that the disruption of the context shift may act to increase the behavioral relevance and thus encoding of context. It is also possible that the context shift creates an event segmentation[13] in the spatiotemporal context, resulting in a greater relation when overlapping pairs are learned within the same context in what is perceived to be the same episode. Future studies should examine the degree to which implicit context shifts between learning of the initial and overlapping pairs and the inference test affect the ability to perform the inference.

Previous work done by Zeithamova et al.[11] posits that memory integration occurs when new learning (BC) cues the reactivation of prior related information (AB) leading to the creation of more overlapping representations. Thus, we hypothesize that the overlapping implicit context may increase reactivation of the initial learning, generating more overlapping memory traces at the time of encoding[9] and allowing for faster inferences through the process of memory integration. However, future work measuring the degree of reactivation of the initial memory at the time of overlapping learning as a function of contextual shift using fMRI is needed to test this hypothesis.

The observed implicit contextual effects on memory integration have important implications in education, where the learning, study, and test environments vary greatly across students. Specifically, the effect of implicit context on the speed of inference performance at test could greatly impact standardized testing which often have strict time limitations. Test such as the MCAT, which present new information at test and ask for test-takers to interpret and respond to questions rapidly could be affected by the original learning context, resulting in unreliable results across individuals and thus failing to compare intelligence in a meaningful way across individuals for admittance to competitive graduate programs. Further, these results support study strategies for standardized tests that encourage students to study or take practice exams in a similar implicit context that they will experience upon testing.

Author Contributions

Alexandra A. Miller, Robert J. Molitor, and Alison R. Preston designed the experiment. Alexandra A. Miller collected and analyzed the data. Alexandra A. Miller, Robert J. Molitor, and Alison R. Preston wrote the manuscript.

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Declaration of conflicting interests

The authors have no conflicts of interest to report.

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